AIR QUALITY MONITORING CONSIDERATIONS FOR THE SOUTH FLORIDA/CARIBBEAN NETWORK

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Introduction

As part of the National Park Service (NPS) Inventory and Monitoring (I&M) Program's Vital Signs scoping process, the South Florida/Caribbean Network (SFCN) will evaluate the need for ambient air quality and air pollution effects monitoring in Network parks. This report contains background and summary air quality information to assist Network staff in that effort. On-site and nearby off-site ambient air quality data were used in conjunction with park-specific resource information to evaluate the following relative to the SFCN: 1) the need for additional ambient air quality monitoring at any Network park, i.e., wet deposition, dry deposition, visibility, and/or ozone monitoring, and 2) the need for air quality effects-related monitoring at any Network park.

The evaluation for SFCN parks relied on data collected through a number of Federal- and state-sponsored ambient air quality monitoring programs. Monitor locations, site numbers, and distances from SFCN parks are provided in Tables 1 and 2. Maps displaying monitor locations and graphics summarizing monitoring data are provided in a separate PowerPoint file as an addendum to this report.

The evaluation used products developed by the NPS Air Resources Division (ARD) specifically for the I&M Program. In 2004, the ARD finalized an Air Quality Inventory for I&M parks. The Air Quality Inventory consists of GIS-based maps and associated look-up tables that provide baseline values for a set of air quality parameters for all I&M parks. The values are based on averaged 1995 to 1999 data. Air Quality Inventory products are in the NPS Air Atlas (http://www2.nature.nps.gov/air/maps/airatlas/). NPS Air Atlas estimates for select air quality parameters for SFCN parks are provided in Appendix 1 of this report, and a description of those parameters is provided in Appendix 2. Because ozone is a regional pollutant, in most cases the estimates are likely representative of ozone concentrations in a park. Greater variability, and uncertainty, may exist for deposition and visibility values, since those pollutants are more likely to be influenced by meteorological differences.

In another project, completed in October 2004, ARD contracted with an ozone effects expert to assess the risk of ozone-induced foliar injury on sensitive vegetation in I&M parks. The risk assessments are based on NPS Air Atlas ozone values, the Palmer Z Drought Index and park vascular plant lists. The assessment for the SFCN is attached as Appendix 3.

Wet Deposition

The National Atmospheric Deposition Program/National Trends Network (NADP/NTN) is a nationwide network of precipitation monitoring sites. The network is a cooperative effort between many different groups, including the U.S. Environmental Protection Agency (EPA), U.S. Geological Survey (USGS), U.S. Department of Agriculture, and private entities. The NPS is a major participant in NADP/NTN, and the ARD recommends that any new wet deposition site installed in a park meet NADP/NTN siting criteria and follow NADP/NTN monitoring protocols. There are currently more than 200 NADP/NTN sites spanning the continental U.S., Alaska, Puerto Rico, and the Virgin Islands (http://nadp.sws.uiuc.edu/).

The purpose of the NADP/NTN network is to collect data on the chemistry of precipitation in order to monitor geographical and temporal long-term trends. The precipitation at each station is collected weekly according to strict clean-handling procedures. It is then sent to the Central Analytical Laboratory in Illinois where it is analyzed for hydrogen (acidity as pH), sulfate (SO_4), nitrate (NO_3), ammonium (NH_4), chloride, and base cations (such as calcium, magnesium, potassium and sodium). NADP/NTN's excellent quality assurance programs ensure that the data remain accurate and precise.

The NADP/NTN has also expanded its sampling to include the Mercury Deposition Network (MDN), which currently has over 85 sites in North America. The MDN was formed in 1995 to collect weekly samples of precipitation, which are analyzed for total mercury. The objective of the MDN is to monitor the amount of mercury in precipitation on a regional basis (http://nadp.sws.uiuc.edu/mdn/).

Deposition varies with the amount of annual on-site precipitation, and is useful because it gives an indication of the total annual pollutant loading at the site. Concentration is independent of precipitation amount, therefore, it provides a better indication of whether ambient pollutant levels are increasing or decreasing over the years. In general, annual average wet deposition and concentration of SO_4, NO_3, and NH_4 are higher in the eastern than in the western U.S. At many NADP/NTN sites across the U.S., concentration and deposition of SO_4 have declined in recent years as sulfur dioxide emissions have decreased. Trends have been variable for NO_3 and NH_4, with concentration and deposition at different sites increasing, decreasing, or showing no overall change. MDN deposition maps show that, similar to SO_4 and NO_3, wet mercury deposition is higher in the eastern U.S. than in the western U.S. Highest wet mercury deposition values are consistently reported for sites in Florida and along the Gulf of Mexico. The MDN program has not yet performed trend analyses for mercury deposition data due to the relatively short time the monitors have been in operation.

Everglades National Park (NP) has both NADP/NTN and MDN monitors on-site and Virgin Islands NP has an on-site NADP/NTN monitor. Big Cypress National Preserve (NPres) and Biscayne NP are within 38 and 30 km, respectively, of the Everglades NP monitors, while Buck Island Reef National Monument (NM) is about 85 km south of the Virgin Islands NP monitor. There are no NADP/NTN or MDN monitors near Dry

Tortugas NP. The average 1995 through 1999 Air Atlas wet deposition values for SFCN parks in Florida were 3.49 to 4.63 kilograms per hectare per year (kg/ha/yr) for sulfur (S) and 2.97 to 3.93 kg/ha/yr for nitrogen (N). The 1999 deposition values at Virgin Islands NP were 2.67 kg/ha for S and 0.99 kg/ha for N, comparable to amounts recorded at the park in 2003. Further information on the Everglades and Virgin Islands NP wet deposition monitors is provided below.

Everglades NP

The NADP/NTN monitor was installed at the park Research Center in 1980 (site FL11). NADP/NTN trend analyses indicate no change in SO_4 concentration or wet deposition, no trend in NO_3 or NH_4 concentration, and slight increases in NO_3 and NH_4 wet deposition. The MDN monitor was installed at the Research Center in 1995 (site FL11). Mercury concentration and wet deposition were substantially higher in 2003 than in previous years.

Virgin Islands NP

A NADP/NTN monitor was installed at the park in 1998 (site VI01). Because the data have not met the program's completeness criteria for most years, NADP/NTN has not performed a trend analysis for the site.

Dry Deposition

The Clean Air Status and Trends Network (CASTNet) is the nation's primary source for atmospheric data to estimate dry acidic deposition (http://www.epa.gov/castnet/). Established in 1987, CASTNet now comprises about 95 monitoring sites across the U.S. The majority of the monitoring stations are operated by EPA; however, approximately 30 stations are operated by the NPS in cooperation with EPA. Each CASTNet dry deposition station measures weekly average atmospheric concentrations of SO_4, NO_3, NH_4, sulfur dioxide, and nitric acid; hourly concentrations of ambient ozone; and some meteorological parameters. Dry deposition rates are calculated using atmospheric pollutant concentrations, meteorological data, and information on land use, vegetation, and surface conditions. CASTNet complements the database compiled by NADP/NTN; therefore, CASTNet sites are located at or near NADP/NTN sites. Dry deposition monitoring is more difficult, and more expensive, than wet deposition monitoring; consequently, there are fewer CASTNet than NADP/NTN sites nationwide. Because CASTNet calculates dry deposition based on estimated deposition velocities, there is greater uncertainty in the reported values than in the values measured by NADP/NTN. CASTNet recently developed ambient concentration isopleth maps (http://www.epa.gov/castnet/mapindex.html), but has not produced similar maps for dry deposition.

Both Everglades and Virgin Islands NPs have/had a CASTNet monitor on-site; data summaries and trend analyses for the sites are provided below. There are no sites near Dry Tortugas NP.

Everglades NP

The Everglades NP CASTNet site was installed at the Research Center in 2000 (site EVE419). 2000 through 2003 data showed no trends in either dry S deposition or dry N

deposition. Total S deposition at Everglades NP was composed of 17 percent dry deposition and 83 percent wet deposition, while total N deposition was 18 percent dry and 82 percent wet.

Virgin Islands NP

The CASTNet site was installed at Lind Point in 1993 and discontinued in 2004 (site VII423). 1999 through 2003 data showed no trends in either dry S deposition or dry N deposition. Total S deposition at the site consisted of 15 percent dry and 85 percent wet deposition, while total N deposition was 18 percent dry and 82 percent wet.

Chemical Analyses of Surface Water, Sediments and Biota

It is generally accepted that surface waters with a pH below 6.0 and an acid neutralizing capacity (ANC) below 100 microequivalents per liter (μeq/l) are sensitive to acidification from atmospheric deposition. The NPS Water Resources Division's *Baseline Water Quality Data Inventory and Analysis* reports were reviewed for all SFCN parks except Dry Tortugas NP, for which a report was not available. In addition, state agency and the NPS Research Permit and Reporting System (RPRS) websites were reviewed for reports of any additional, relevant surface water or sediment chemistry data. The websites were also reviewed for information pertaining to any chemical analyses conducted on biota in the park. The results are summarized below.

Acidification due to atmospheric deposition does not appear to be a threat to surface waters of any SFCN parks. Eutrophication from nitrogen deposition is a concern in many coastal areas, and may be an issue for the SFCN, particularly in Biscayne and Everglades NPs. Florida has fish consumption advisories to limit ingestion of mercury from fish. Advisories are in effect for water bodies in Collier, Monroe and Miami-Dade counties, which encompass Big Cypress NPres, Biscayne NP and Everglades NP (http://www.doh.state.fl.us/environment/community/fishconsumptionadvisories/index.html). It does not appear that Virgin Islands has issued any fish consumption advisories (http://www.dpnr.gov.vi/dep/home.htm). A number of studies relative to mercury and other pollutants have been conducted in SFCN parks.

The U.S. Department of Agriculture (USDA) collected weekly ambient air, rain and surface water samples in 2002-2003 to determine whether pesticides are entering south Florida waters through atmospheric deposition. A number of pesticides were detected in the samples. Higher concentrations were found in air, rain and surface water during harvest (March) than during the planting season (November). Pesticide concentrations were lower in samples collected at Biscayne NP than in those from Everglades NP. (Kathleen Hapeman, USDA, 301-504-6511)

The Science Museum of Minnesota collected sediment cores from Florida lakes, and used ^{210}Pb-dating to try to evaluate changes in atmospheric mercury deposition over time and to distinguish mercury deposition resulting from local versus global sources. They were not successful in obtaining a core from Deep Lake in Big Cypress NPres, but they did get a core from Nine-Mile Pond in Everglades NP and from three other Florida lakes. Mercury concentrations and deposition varied between sites. A core from a central

Florida lake indicated a decrease in mercury deposition over time, while cores from south Florida lakes showed no change in deposition. (Dan Engstrom, The Science Museum of Minnesota, 651-433-5953)

The USGS collected sediment cores at Big Cypress NPres and Everglades NP in 2002-2003 to examine mercury, S and nutrient cycling. Results were not provided on the RPRS website. (Ben McPherson, USGS, 813-975-8620)

The South Florida Water Management District collected water and sediment samples from Everglades NP in 2000-2001 and analyzed them for total and methylmercury. They found a pattern of elevated concentrations of methylmercury where runoff mixed with saline bay waters. This indicated a local source of methylmercury formation. (Darren Rumbold, South Florida Water Management District, 561-682-2132)

Long-term monitoring of mercury concentrations in largemouth bass and other fish has taken place in Everglades NP and peninsular Florida. Sampling began in Everglades NP in 1989. Fish mercury concentrations appear to increase from north to south in the park. Fish from North Prong Creek in Everglades NP and from Big Lostmans/Indian Camp Creek in the drainage basin of Big Cypress NPres exceeded Florida's "no consumption" threshold in 2001, 2002 and 2003. Results from earlier years were not reported on the RPRS website. (Ted Lange, 352-742-6461)

The South Florida Water Management District evaluated mercury concentrations in mosquitofish, sunfish and largemouth bass collected at Everglades NP in 2002-2004. While increased concentrations were observed between 2002 and 2003, the reason for, and significance of, the change is unknown. 2004 results were not provided on the RPRS website. (Nicole Niemeyer, South Florida Water Management District, 561-753-2400)

The USGS collected pig frogs (*Rana grylio*) in Everglades NP in 2001 and measured total mercury concentrations in frog leg muscle. They reported a maximum concentration of 2.3 mg/l (wet mass). (Kenneth Rice, USGS, 954-577-6305)

A researcher collected blood samples from eaglets and osprey nestlings at Everglades NP in 2003 to determine mercury levels in serum. No results were provided on the RPRS website. (Brian Mealey, 305-975-0200)

P.E.A.K. Research quantitatively evaluated pre-1992 and 2002 risks of chronic dietary mercury exposure to panthers in the Everglades. They determined that pre-1992, there was a 46 percent probability of exceeding chronic dietary thresholds for methylmercury. The 2002 risk was a 4 percent probability of exceedances. P.E.A.K. Research concluded that past mercury exposures likely adversely affected panthers in the Everglades, but that current risks from mercury are low. (Barron, M.G., S.E. Duvall, and K.J. Barron. 2004. Retrospective and current risks of mercury to panthers in the Florida Everglades. **Ecotoxicology** 13:223-229)

The Academy of Natural Sciences and others investigated factors that control aquatic cycling of mercury in the Everglades. Using a process-oriented, multidisciplinary approach that involved a number of intensively-studied sites in the Everglades, the investigators determined that: 1) mercury methylation in the Everglades is mediated by sulfate-reducing bacteria in the soil, 2) methylmercury bioaccumulation occurs primarily through the benthic food web, 3) S has the largest impact on methylmercury production, but the magnitude and direction of the impact vary with S concentration, and 4) phosphate and NO_3 have no direct effect on methylmercury production rates in sediment cores. (Cynthia Gilmour, The Academy of Natural Sciences, 410-586-9713)

The Florida Department of Environmental Protection (FDEP) used emissions, deposition and fish and wildlife data to show that a decline in local mercury emissions resulted in reduced mercury concentrations in Everglades wildlife. There was a significant reduction in mercury emissions in Dade, Broward and Palm Beach counties in about 1990. Analysis of lake cores showed a mercury reduction at about the same time. Mercury concentrations in egret feathers decreased between 1994 and 2003, approaching pre-1980 levels. Mercury concentrations in largemouth bass and mosquitofish also declined in the 1990s. The FDEP concluded a decline in local atmospheric mercury emissions resulted in a 75 percent decline in mercury concentrations in fish and wildlife in less than 15 years from peak deposition. They further concluded that atmospheric deposition drives the Everglades mercury problem. (Tom Atkeson, FDEP, 850-245-8305)

Particulate Matter

Small or "fine" particles in the air, typically those less than 2.5 microns in diameter, $PM_{2.5}$, are a leading cause of human respiratory illness. Particles are present everywhere, but high concentrations and/or specific types have been found to present a serious danger to human health. Fine particles in the air are also the main contributor to human-caused visibility impairment. The particles not only decrease the distance one can see; they also reduce the colors and clarity of scenic vistas.

The pre-existing human-health based National Ambient Air Quality Standards (NAAQS) for particulate matter (set by the EPA) are for particles 10 microns or less in diameter (PM_{10}). Areas where air quality exceeds the NAAQS are designated "nonattainment" for that pollutant. Only Buck Island Reef NM and Everglades NP have nearby PM_{10} monitors. In 1997, EPA finalized an additional, stricter NAAQS for particulate matter based on $PM_{2.5}$. Nationwide $PM_{2.5}$ monitoring was initiated in 1999. $PM_{2.5}$ monitors are located near all SFCN parks except Big Cypress NPres and Dry Tortugas NP. Neither Florida nor Virgin Islands have designated PM_{10} or $PM_{2.5}$ nonattainment areas (http://www.epa.gov/air/data/index.html).

In 2001, the USGS began investigating potential ecological effects in the Caribbean due to dust storms that originate in Africa. Air samples taken during dust storms at Dry Tortugas and Virgin Islands NPs contained bacteria, fungi, heavy metals and persistent organic pollutants. Laboratory studies indicate the dust could be toxic to some marine organisms. (Virginia Garrison and Dale Griffin, USGS, 727-803-8747)

Visibility

In 1985, in response to the mandates of the Clean Air Act, Federal and regional/state organizations established the Interagency Monitoring of Protected Visual Environments (IMPROVE) program to protect visibility in Class I air quality areas. Class I areas are national parks greater than 5,000 acres and wilderness areas greater than 6,000 acres, that were established prior to August 7, 1977. All other NPS areas are designated Class II. Everglades and Virgin Islands NPs are Class I areas. The objectives of the IMPROVE program are to: establish current visibility conditions in all Class I areas, identify pollutants (particles and gases) and emission sources responsible for existing man-made visibility impairment, and document long-term trends in visibility. The IMPROVE network is designed to assess regional visibility; standard operation does not identify individual sources that impair visibility at a monitoring site.

In 1999, there were 30 official IMPROVE sites and 40 protocol sites. Because of recently enacted Regional Haze regulations that require improving visibility in Class I areas, the number of visibility monitors has increased. Protocol sites were upgraded to full IMPROVE sites and 80 new sites were added to the IMPROVE network. While the IMPROVE program has focused on Class I air quality areas, a great deal of visibility monitoring has been conducted in Class II areas. Installation and annual operating costs for a full IMPROVE site are expensive. The ARD is currently developing a monitoring protocol for less-expensive view monitoring using a digital camera. While this type of monitoring would not be adequate for regulatory purposes, it is useful for documenting visibility conditions and trends and presents an excellent means of sharing that information with the public.

IMPROVE provides maps of visibility conditions, pie charts of the pollutants that contribute to visibility impairment, and trend data for sites that have been operating 10 years or longer (http://vista.cira.colostate.edu/views/). One measurement used to report visibility is light extinction, or b_{ext}, reported in inverse megameters (Mm^{-1}). Light extinction occurs when particles in the air scatter or absorb light; extinction generally increases as particle concentrations in the air increase. Therefore, the higher the b_{ext}, the worse the visibility. The Regional Haze regulations require improvements in visibility on both the best (clearest), and the worst (haziest), days. In general, visibility is much better in the western, than in the eastern, U.S.

Everglades and Virgin Islands NPs have on-site IMPROVE monitors. The Everglades site, EVER1, has been operating since 1988 while the Virgin Islands site, VIIS1, has been operating since 1998. No monitors are located near Dry Tortugas NP.

The average 1995 to 1999 estimates provided in the NPS Air Atlas indicate values at Florida SFCN parks of 38 to 39 Mm^{-1} on the best visibility days and 151 to 155 Mm^{-1} on the worst visibility days. 2003 IMPROVE data indicated b_{ext} at Florida SFCN parks on the best visibility days ranged from 23 to 27 Mm^{-1}. On the worst visibility days, b_{ext} at south Florida parks ranged from 72 to 90 Mm^{-1}. Everglades NP 2003 IMPROVE data show that on the clearest days, impairment was due to ammonium sulfate (52 percent),

organic carbon (17 percent) and ammonium nitrate (12 percent). On the haziest days, impairment was due mostly to organic carbon (49 percent) and ammonium sulfate (38 percent). Sources of ammonium sulfate include coal combustion and oil refineries; sources of ammonium nitrate are coal and natural gas combustion and automobiles; and sources of organic carbon include automobiles. The other constituents that contribute to visibility impairment are elemental carbon (from wood burning) and coarse mass (source unknown). 1990 through 2003 trend analyses for Everglades NP show improvements on both the clearest and haziest days through 2002, but substantial deterioration in 2003.

Ozone

Ozone is created by a chemical reaction between oxides of nitrogen and volatile organic compounds in the presence of heat and sunlight. Some major sources of ozone-forming chemicals are motor vehicle exhaust and industrial emissions, gasoline vapors, and chemical solvents. High ozone concentrations cause respiratory problems in humans, and are a particular concern for those who are engaging in strenuous aerobic activity, such as hiking. Ozone also damages sensitive plant species. It injures plant leaves by causing a visible spotting or "stipple" on the upper surface of the leaves. Ozone can affect plant physiology by reducing growth, increasing susceptibility to disease, and increasing senescence.

Everglades and Virgin Islands NPs have an ozone monitor on-site; Buck Island Reef NM and Dry Tortugas NP have no nearby monitors (http://www.epa.gov/air/data/index.html). EPA recently established a new NAAQS for ozone which is based on an 8-hour ozone concentration. The previous, less-stringent, NAAQS was based on a 1-hour concentration. There are no 1-hour or 8-hour ozone nonattainment areas in either Florida or Virgin Islands (http://www.epa.gov/ttn/naaqs/ozone/index.html).

The NPS focuses on plant sensitivity to ozone for a couple of reasons. First, ozone is a regional pollutant and is, therefore, more likely to affect park resources than other gaseous pollutants such as sulfur dioxide and nitrogen oxide which quickly convert to other compounds. Second, the literature on ozone sensitivity is more recent and more reliable than that for other pollutants. The ARD contracted with an ozone effects expert from Cornell University to perform ozone injury risk assessments for all parks in the NPS I&M program. The risk assessments relied on the ozone concentration data provided in Air Atlas, vascular plant lists contained in NPSpecies, a master list of ozone-sensitive vascular plant species developed at a 2003 expert workshop convened by the ARD (http://www2.nature.nps.gov/air/Pubs/index.htm), and the Palmer Z Index, which is used to indicate soil moisture status. Note that the ARD workshop report provides a general guide to ozone sensitivity. Differences in plant genetics, weather conditions, soil water availability, and ozone concentrations will affect whether or not a species exhibits injury in a park. In particular, studies have shown that plants will not take up ozone unless there is sufficient soil moisture. The risk assessments for the SFCN parks are in Appendix 3. An assessment could not be performed for Dry Tortugas NP due to the lack of ambient ozone data. For the remaining SFCN parks, there is a low risk of ozone-induced foliar injury of sensitive vegetation.

Conclusions

Except for Dry Tortugas NP, all SFCN parks have both wet and dry deposition monitors on-site or nearby. Given the remoteness of Dry Tortugas and lack of acid-sensitive surface waters, monitoring deposition at the park is not warranted. Only the south Florida SFCN parks have an on-site or nearby MDN monitor. Installation of additional MDN monitors is not recommended at this time.

Data indicate surface waters in SFCN parks are not susceptible to acidification from atmospheric deposition; however, atmospherically-deposited N could be a concern from an eutrophication standpoint. Atmospherically-deposited mercury is a significant concern in south Florida, as numerous studies have shown elevated methylmercury concentrations in fish and other biota. While reductions in mercury emissions have led to substantial reductions in mercury deposition and tissue methylmercury levels since 1990, continued monitoring of mercury levels in biota is recommended.

$PM_{2.5}$ and/or PM_{10} are monitored near all SFCN parks except Big Cypress NPres and Dry Tortugas NP. All parks except Dry Tortugas have on-site or nearby IMPROVE monitoring. Because of the remoteness of the area, monitoring particulates at Dry Tortugas NP is not warranted. If visibility impairment is of particular interest for any Network park, the SFCN may want to consider installing a digital camera to record and interpret visibility conditions. Given concerns about African dust storms, the Network may want to consider ambient monitoring of dust events for toxic pollutants and/or biological agents.

Except for Buck Island Reef NM and Dry Tortugas NP, all SFCN parks have an on-site or nearby ozone monitor. Given the low ozone values recorded at, or estimated for, the other Network parks, monitoring ozone at Buck Island Reef and Dry Tortugas is not warranted at this time. The ozone injury risk assessments indicate a low risk of ozone injury of sensitive vegetation in SFCN parks. Therefore, foliar injury surveys are not recommended for Network parks.

Table 1. Summary of Deposition Data Collected in and near National Park Service Units in the South Florida/Caribbean Network

PARK	NADP/NTN		CASTNet		MDN	
	LOCATION	SITE #	LOCATION	SITE #	LOCATION	SITE #
BICY	Everglades National Park 38 km SE	FL11	Everglades National Park 38 km SE	EVE419	Everglades National Park 38 km SE	FL11
BISC	Everglades National Park 30 km W	FL11	Everglades National Park 30 km W	EVE419	Everglades National Park 30 km W	FL11
BUIS	Virgin Islands National Park 85 km N	VI01	Virgin Islands National Park 85 km N	VII423	None	----
DRTO	None	----	None	-----	None	----
EVER	On-site	FL11	On-site	EVE419	On-site	FL11
VIIS	On-site	VI01	On-site	VII423	None	----

NADP/NTN = National Atmospheric Deposition Program/National Trends Network
CASTNet = Clean Air Status and Trends Network
MDN = Mercury Deposition Network
BICY = Big Cypress National Preserve
BISC = Biscayne National Park
BUIS = Buck Island Reef National Monument
DRTO = Dry Tortugas National Park
EVER = Everglades National Park
VIIS = Virgin Islands National Park

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Table 2. Summary of Ozone, IMPROVE and PM Data Collected in and near NPS Units in the South Florida/Caribbean Network

PARK	OZONE		IMPROVE		PM	
	LOCATION	**SITE #**	**LOCATION**	**SITE #**	**LOCATION**	**SITE #**
BICY	Everglades NP 38 km SE	12-086-0030- 44201-1	Everglades NP 38 km SE	EVER1	None	----
	Naples, FL 45 km W	12-021-0004- 44201-1				
BISC	Hialeah, FL 20 km NW	12-086-0029- 44201-1	Everglades NP 30 km W	EVER1	Hialeah, FL 20 km NW ($PM_{2.5}$)	12-086-6001- 88101-1
	Everglades NP 30 km W	12-086-0030- 44201-1				
BUIS	None	----	Virgin Islands NP 85 km N	VIIS1	Manning Bay, St. Croix, VI Within 20 km SW ($PM_{2.5}$ and PM_{10})	78-001-0012- 88101-1 and 78-001-0008- 81102-1
DRTO	None	----	None	----	None	----
EVER	On-site	12-086-0030- 44201-1	On-site	EVER1	Hialeah, FL 20 km E ($PM_{2.5}$)	12-086-6001- 88101-1
VIIS	On-site	78-003-0001- 44201-1	On-site	VIIS1	Charlotte Amalie, St. Thomas, VI Within 20 km W ($PM_{2.5}$ and PM_{10})	78-005-0009- 88101-1 and 78-005-0004- 81102-1

IMPROVE = Interagency Monitoring of Protected Visual Environments Visibility Monitoring Program
PM_{10} = Particulate matter less than 10 microns in diameter
$PM_{2.5}$ = Particulate matter less than 2.5 microns in diameter
BICY = Big Cypress National Preserve
BISC = Biscayne National Park
BUIS = Buck Island Reef National Monument
DRTO = Dry Tortugas National Park
EVER = Everglades National Park
VIIS = Virgin Islands National Park

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Appendix 1. Air Atlas Pollution Estimates

South Florida/Caribbean Network

	Ozone					Wet Deposition NADP		Visibility Mm-1	
Park	2nd_Hi_1hr	4th_Hi_8hr	#8hr_>_85	#1hr_>_100	Sum06_3_Mo	Total_S_kg/ha	Total_N_kg/ha	B_{ext}_Clear	Mm-1 B_{ext}_Hazy
BICY	99.8	70.2	1.9	1.9	7.2	3.16	2.61	39	151
BISC	101.2	70.2	1.9	2.0	7.1	3.33	2.81	38	155
BUIS*									
DRTO	99.9	70.0	1.9	1.9	5.7	3.35	2.84	38	154
EVER	99.9	70.0	1.9	1.9	5.7	3.35	2.84	38	154
VIIS*									

*Values cannot be estimated due to scarcity of nearby monitors

Ozone information represents 5-yr average of annual values from 1995-1999

2nd_Hi_1hr concentration (ppb): indicates peak values for ozone; old standard of 0.12 ppm (120 ppb) was based on 2nd hi,1-hr average

4th_High_8hr concentration (ppb): new ozone standard of 0.08 ppm (80 ppb) is based on 4th hi, 8-hr average

#8_hr_>_85: indicates how often the area would be in violation of the new 8-hr standard of 80 ppb

1hr_>_100: high peaks in ozone concentration, as well as cumulative dose, contribute to vegetation injury

SUM06_3_Mo (ppm-hrs): sum of hourly ozone conc.≥0.06 ppm (60 ppb) over 3 months (~ growing season), i.e., cumulative ozone dose

Wet Depostion information represents 6-yr average of annual values from 1995-2000

NADP (kg/ha/yr): estimate of pollutants deposited to ecosystem by precipitation (NADP-National Atmospheric Deposition Program)

Total_S_kg/ha: sulfur from sulfate deposited by precipitation

Total_N_kg/ha: inorganic nitrogen (ammonium plus nitrate) deposited by precipitation

Visibility information represents 5-yr average of annual IMPROVE Program values from 1995-1999

B_{ext}_Clear: measure of light scattering and absorption, i.e., extinction, by particles in the air on an average clear day

B_{ext}_Hazy: measure of light scattering and absorption, i.e., extinction, by particles in the air on an average hazy day

Appendix 2. Description of Parameters Used in Air Atlas Summary Tables

The Air Atlas is a mini-GIS tool available on the Internet that provides national maps and an associated look-up table with baseline values of air quality parameters for all Inventory and Monitoring (I&M) parks in the U.S. The values are based on averaged 1995-1999 data. Air Atlas was produced by the National Park Service Air Resources Division (ARD) in association with the University of Denver. Air Atlas will serve as the Air Inventory for the parks and is available on the Internet at http://www2.nature.nps.gov/ard/gas/ (see section called *Air Atlas*).

The estimated air quality values provided in the look-up table are based on the center of the polygon defining the park or multiple units of the park. Because ozone is a regional pollutant, in most cases the look-up table values are likely representative of ozone concentrations throughout the park. Greater variability may exist for other parameters, such as deposition and visibility. In the future, the full Air Atlas dataset will be available on the internet, and users of ArcView and ArcGIS will be able to obtain air quality values for multiple points in a park by entering the latitude and longitude coordinates.

Air Atlas contains a comprehensive set of air quality parameters for all I&M parks. In addition, ARD has prepared a summary table that includes a select group of air quality parameters for each I&M network. The summary version is intended to provide parks with a synopsis useful for characterizing air quality conditions. Air quality parameters selected for the summary version are described below.

Ozone Parameters

Ozone can be expressed as concentration or cumulative dose. Relevant concentration and dose parameters include:

2nd Hi 1-hr: expressed in parts per billion (ppb), this value is the 2nd highest hourly value in a year and can be compared to the former Environmental Protection Agency (EPA) human health-based standard for ozone of 125 ppb (0.12 ppm).

4th Hi 8-hr: expressed in parts per billion (ppb), this value is the average hourly value in the 4th highest 8 hour period and can be compared to the present EPA human health-based standard for ozone of 85 ppb (0.08 ppm).

8 hrs > 85 ppb: indicates how often the site would exceed the present ozone standard.

1 hr > 100 ppb: indicates how often the site experiences high ozone concentrations; high concentrations contribute to vegetation (foliar) injury in sensitive plant species.

SUM06_3Mo: The running 90-day maximum sum of the 0800-2000 hourly concentrations of ozone equal to or greater than 0.06 ppm; represents cumulative exposure dose of ozone to plants.

Ozone is one of the most widespread air pollutants. Ozone is not emitted directly from smokestacks or vehicles, but is formed when other pollutants, primarily nitrogen oxides and volatile organic compounds, react in the atmosphere in the presence of sunlight, usually during the warm summer months. In addition to harming human health, ozone is phytotoxic, and causes considerable damage to vegetation throughout the world, including agricultural crops and native plants in natural ecosystems. The Environmental Protection Agency has established an ozone standard to protect human health; however, EPA has not set a standard to protect vegetation and there is much evidence to suggest that the human health-based standard is not protective of sensitive vegetation.

Ozone enters plants through leaf stomata and oxidizes plant tissue, causing changes in biochemical and physiological processes. Both visible foliar injury (e.g., stipple and chlorosis) and growth effects (e.g., premature leaf loss, reduced photosynthesis, and reduced leaf, root, and total dry weights) can occur in sensitive plant species. In a natural ecosystem, many other factors can ameliorate or magnify the extent of ozone injury at various times and places such as soil moisture, presence of other air pollutants, insects or diseases, and other environmental stresses.

Ozone injury can be induced by a sufficiently high seasonal dose of ozone (expressed as SUM06, in ppm-hrs), high peak concentrations of ozone (expressed in ppb), or a combination of both. Ozone effects to natural vegetation have been documented throughout the country, particularly in many areas of the East and in California. For sensitive natural vegetation in the East, researchers have recommended SUM06 effects endpoints of 8-12 ppm-hrs for foliar injury and 10-15 ppm-hrs for growth effects on tree seedlings in natural forest stands. In the West (Lassen Volcanic, Sequoia/Kings Canyon, and Yosemite NPs), researchers have found that foliar injury on ponderosa and Jeffrey pines ranges from about 15-50 percent at ozone values between 25-30 ppm-hrs. Sites with values above these endpoints may be at risk for vegetation injury if sensitive species are present. However, to adequately assess risk, other factors, including temperature and soil moisture, must be considered. In conditions of low moisture, for example, stomates may close, preventing ozone uptake. Ozone peak concentrations exceeding 100 ppb are also considered to be important in inducing injury and the number of hours in a year above 100 ppb may be significant for evaluating risk.

Atmospheric Deposition Parameters

Atmospheric deposition is the process by which airborne particles and gases are deposited to the earth's surface either through wet deposition (rain or snow), occult deposition (cloud or fog), or as a result of complex atmospheric processes such as settling, impaction, and adsorption, known as dry deposition. Although it is important to know total deposition, (i.e., the sum of wet, occult, and dry deposition) to park ecosystems, often only the wet deposition component is known, as it is the only one that is monitored routinely and extensively across the U.S. (at over 200 sites), as part of the National Atmospheric Deposition Program (NADP). Dry deposition is monitored at about 70 sites as part of the Clean Air Status and Trends Network (CASTNet). Clouds and fog may contribute significantly to total deposition at certain locations (e.g., high elevation areas and areas that experience a high frequency of clouds and fog), but

monitoring cloud and fog deposition is difficult and is done at only a couple of locations in the U.S. Acids, nutrients, and toxics are the primary compounds within deposition that are of concern in park ecosystems.

Deposition can be expressed as concentration (e.g., micrograms per cubic meter or milligrams per liter) or deposition rates (e.g., kilograms per hectare per year – kg/ha/yr). Deposition rates are included in Air Atlas summaries, as these rates best characterize the amount of deposition an ecosystem experiences.

NADP dep (kg/ha/yr): pollutant ions in wet deposition from rain or snow are measured by the National Atmospheric Deposition Program (NADP) and expressed as kg/ha/yr. NADP measures a comprehensive suite of anions and cations; deposition rates of total wet sulfur (S) and total wet inorganic nitrogen (N) (ammonium plus nitrate ions) are included in the summaries.

NADP Total S (kg/ha/yr): total sulfur from sulfate ions in wet deposition.

NADP Total N (kg/ha/yr): total inorganic nitrogen from ammonium and nitrate ions in wet deposition.

Atmospheric deposition affects ecosystems in a variety of ways, including acidification, fertilization or eutrophication, and accumulation of toxics. Acid deposition from sulfur and nitrogen compounds affects freshwater lakes, streams, and watersheds. Acid deposition effects include changes in water chemistry that affect algae, fish, submerged vegetation, and amphibian and aquatic invertebrate communities. Deposition can also cause changes in soil that affect soil microorganisms, understory plants, and trees. Excess nitrogen deposition can cause unwanted fertilization effects, leading to changes in plant community structure and diversity. In estuaries and coastal waters, nitrogen can cause algae blooms, decreases in dissolved oxygen, and loss of seagrasses (i.e., eutrophication).

All areas of the country are experiencing levels of atmospheric deposition above natural levels. The ability of ecosystems to deal with increased levels of deposition varies widely. High elevation ecosystems in the Rocky Mountains, Cascades, Sierra Nevada, southern California, and eastern U.S. are generally the most sensitive to atmospheric deposition due to their poor ability to neutralize acid deposition. Other sensitive areas include the upper Midwest, New England, and Florida, including the shallow bays and estuaries along the Atlantic and Gulf Coasts. Streams in both Shenandoah and Great Smoky Mountains NPs are experiencing chronic and episodic acidification and brook trout fisheries in Shenandoah have been affected. Rocky Mountain NP is also currently undergoing subtle changes in aquatic and terrestrial ecosystems attributable to atmospheric deposition. In some areas, excess nitrogen deposition has caused shifts in plant species composition, with native species being replaced by invasive and exotic species that are better able to utilize nitrogen.

Visibility Parameters

A number of visibility indices, or measurements, can be used to express visibility conditions. The measurement used in Air Atlas summaries is light extinction.

bextClear: annual average light extinction, expressed in inverse megameters, on the 20 percent clearest days

bextHazy: annual average light extinction, expressed in inverse megameters, on the 20 percent haziest days

Light extinction, expressed in the form of inverse megameters (Mm^{-1}), is proportional to the amount of light lost because of scattering or absorption by particles in the air as the light travels over a million meters (one million meters = one megameter). Light extinction occurs when particles in the air scatter or absorb light; extinction generally increases as particle concentrations in the air increase.

Extinction can be measured directly, with a transmissometer and nephelometer, or it can be calculated from representative aerosol measurements. Air Atlas extinction estimates, so-called "reconstructed" estimates, are calculated from aerosol measurements. Total extinction is the sum of the individual extinctions caused by gases, particles, and air molecules in the atmosphere. Relative humidity, as well as particle concentrations, is considered in the equation, as relative humidity increases the extinction efficiency of certain particles.

Light extinction is averaged for the 20 percent clearest and the 20 percent haziest days in an area. The Environmental Protection Agency's 1999 Regional Haze Regulations require that reasonable progress be made to restore visibility to natural background conditions within 60 years. States are to establish goals for each Class I area to improve visibility on the haziest days (defined as the 20 percent haziest day) and ensure no degradation occurs on the clearest days (defined as the 20 percent clearest days). Emissions reductions that benefit visibility in Class I areas are also expected to benefit visibility in all other areas.

Visual range (VR) is another index used to describe visibility. Because VR is not particularly useful for assessing the quality of scenic vistas (clarity, color), light extinction is used in Air Atlas. However, VR is sometimes useful for describing visibility to the general public. VR is expressed as length; extinction is expressed as 1/length. The relationship between VR and extinction is:

$$VR = \frac{3.912}{bext(km^{-1})} = \frac{3912}{bext(Mm^{-1})}$$

Appendix 3. OZONE INJURY RISK ASSESSMENT

SOUTH FLORIDA / CARIBBEAN NETWORK

OCTOBER 2004

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE SOUTH FLORIDA / CARIBBEAN NETWORK

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious

levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone $\geq$ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations $\geq$ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations $\geq$ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours $\geq$ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to –4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

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SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE SOUTH FLORIDA / CARIBBEAN NETWORK

Park	Code	State	Risk	O3 Data
Big Cypress N PRES	BICY	FL	low	kriged
Biscayne NP	BISC	FL	low	kriged
Buck Island Reef NM	BUIS	VI	low	kriged
Dry Tortugas NP	DRTO	FL	cannot eval	no data
Everglades NP	EVER	FL	low	monitored
Virgin Islands NP	VIIS	VI	low	monitored

BIG CYPRESS NATIONAL PRESERVE
(BICY)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Sambucus canadensis	American elder	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for BICY					
	1995	1996	1997	1998	1999
Sum06	4	4	5	15	10
W126	7.1	6.9	9.4	17.6	10.3
N60	100	87	129	301	158
N80	10	7	14	47	22
N100	1	1	1	5	2

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at BICY					
	1995	1996	1997	1998	1999
Month 1	-0.34	-1.12	-0.60	2.28	-1.24
Month 2	1.29	1.31	2.96	-1.33	-1.48
Month 3	-0.61	-0.07	0.08	-1.84	-1.02

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at BICY					
	1995	1996	1997	1998	1999
April	1.29	-0.07	2.96	-1.33	-1.02
May	-0.61	3.12	0.08	-1.84	-0.63
June	2.32	0.30	0.17	-3.10	3.51
July	3.23	-3.04	0.86	-1.21	-0.10
August	4.63	-1.25	-1.37	-0.05	-0.23
September	0.26	-2.71	-0.75	0.10	2.18
October	6.92	1.31	-2.34	-1.85	2.91

Risk Analysis

- There are two ozone-sensitive species at the site, but neither of them is a bioindicator for ozone.

- The Sum06 index is generally below the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations often exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than five hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- The low levels of ozone during the 90-day Sum06 accumulation periods make it difficult to assess relationships between the levels of ozone and soil moisture, however they appear to be inversely related: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The years with the highest and second highest ozone exposures, 1998 and 1999 respectively, experienced two and three months of mild drought, while the remaining three years, with lower ozone exposures, had one month of mild drought among them. Soil moisture levels associated with the seasonal W126 index also appear to be inversely related to

ozone concentrations, although the pattern is not consistent. In the highest ozone year, 1998, there were five months of mild and severe drought. The two mid-level exposure years, 1999 and 1997, had one and two months of mild and moderate drought respectively, while the second lowest year, 1995, had normal soil moisture and the lowest year, 1996, had three months of mild to severe drought.

The low levels of ozone exposure and the relatively dry soil moisture conditions at Big Cypress National Preserve make the risk of foliar ozone injury to plants low. The Sum06 criteria are generally not satisfied, while the W126 are not fulfilled. Hourly concentrations of ozone seldom exceed 80 ppb, and exposure to 100 ppb is rare. The inverse relationship between exposure and soil moisture constrains the uptake of ozone in high exposure years and further reduces the likelihood of foliar injury.

While ozone-sensitive species occur at the site, they are not bioindicator species.

BISCAYNE NATIONAL PARK
(BISC)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Parthenocissus quinquefolia	Virginia creeper	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
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	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
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Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for BISC					
	1995	1996	1997	1998	1999
Sum06	4	4	4	14	9
W126	7.7	7.5	9.2	16.3	10.8
N60	111	93	118	270	168
N80	17	11	19	44	25
N100	2	2	1	4	3

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at BISC					
	1995	1996	1997	1998	1999
Month 1	0.23	1.32	0.12	3.09	-1.66
Month 2	0.46	-0.05	-0.46	-1.55	-1.88
Month 3	0.33	1.54	0.72	-1.58	-1.56

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at BISC					
	1995	1996	1997	1998	1999
April	0.33	-0.05	0.72	-1.55	-1.88
May	-1.91	1.54	-0.79	-1.58	-1.56
June	3.30	1.74	3.27	-2.45	4.22
July	1.11	-2.27	-0.02	-1.07	-1.79
August	6.71	-0.51	1.71	-0.38	3.63
September	-0.84	-1.10	1.60	2.51	0.25
October	2.22	1.30	-2.80	-2.27	4.13

Risk Analysis

- There is one ozone-sensitive species listed for the site.
- The Sum06 index is generally below the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than four hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.
- The low levels of ozone during the 90-day Sum06 accumulation periods make it difficult to assess relationships between the levels of ozone and soil moisture, however they appear to be inversely related, when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The two highest ozone years, 1998 and 1999, had two and three months of mild drought, respectively. The remaining three years had lower levels of exposure and favorable soil moisture throughout. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure, but again the pattern is not consistent. There were five months of mild and moderate

drought in 1998, the year with the highest exposure. In 1999 and 1997, years with mid-level exposures, there were four months of mild and severe drought and one month of moderate drought, respectively. The second lowest year, 1995, had one month of mild drought, and the lowest year, 1996, had two months of mild and moderate drought.

The low levels of ozone exposure and soil moisture conditions at Biscayne National Park make the risk of foliar ozone injury to plants low. The Sum06 exposures generally do not exceed the threshold for injury, and the W126 exposures do not since the N100 requirement is not satisfied. Hourly concentrations of ozone seldom exceed 80 ppb, and exposure to 100 ppb is rare. The inverse relationship between exposure and soil moisture constrains the uptake of ozone in higher exposure years and further reduces the likelihood of foliar injury.

While one ozone-sensitive species occurs at the site, it is not a bioindicator species.

BUCK ISLAND REEF NATIONAL MONUMENT (BUIS)

Plant Species Sensitive to Ozone

No sensitive species are listed for the site.

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for BUIS

	1995	1996	1997	1998	1999
Sum06	14	10	10	16	22
W126	25.7	23.8	26.1	34.6	38.8
N60	399	379	438	601	714
N80	36	23	19	42	54
N100	4	2	1	2	4

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data are not available for the area. Therefore, it is not possible to assess the relationship between ozone exposure and drought and to evaluate the possible effects of drought stress on the uptake of ozone at the site.

Risk Analysis

- There are no ozone-sensitive species listed for the site.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.
- The N-values for the site show concentrations frequently exceed 60 ppb and occasionally exceed 80 ppb. No year has more than four hours in which the concentration exceed 100 ppb. These levels of exposure are not likely to injure vegetation.
- Palmer Z index data are not available for the region in which the site is located. Consequently, relationships between ozone exposure and soil moisture cannot be assessed.

The low levels of ozone exposure at Buck Island Reef National Monument make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold level for injury, the W126 do not since the N100 requirement is not satisfied. Hourly concentrations of ozone occasionally exceed 80 ppb while exposure to 100 ppb is rare. The possible role of soil moisture in constraining the uptake of ozone is unknown, but any drought would further reduce the likelihood of foliar injury.

No ozone- sensitive species are listed for the site.

DRY TORTUGAS NATIONAL PARK
(DRTO)

Plant Species Sensitive to Ozone

No sensitive species are listed for the site.

Ozone Exposure Data

No ozone exposure data are available for the site.

Soil Moisture Status

The US Department of Agriculture's Palmer Z Index that was selected to indicate soil moisture status does not include this site that is over 60 miles offshore.

Risk Analysis

The risk of ozone injury on foliage of vegetation at Dry Tortugas National Park cannot be assessed due to the lack of information on ozone exposure at the site.

EVERGLADES NATIONAL PARK
(EVER)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Spartina alterniflora	Smooth cordgrass	Poaceae
Sambucus canadensis	American elder	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for EVER					
	1995	1996	1997	1998	1999
Sum06	2	2	2	13	4
W126	2.8	2.8	4.2	11.5	25.1
N60	33	27	43	208	97
N80	3	6	9	17	15
N100	0	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at EVER					
	1995	1996	1997	1998	1999
Month 1	0.04	-1.12	-0.60	2.28	-1.24
Month 2	-0.34	1.31	2.96	-1.33	-1.48
Month 3	1.29	-0.07	0.08	-1.84	-1.02

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at EVER					
	1995	1996	1997	1998	1999
April	1.29	-0.07	2.96	-1.33	-1.02
May	-0.61	3.12	0.08	-1.84	-0.63
June	2.32	0.30	0.17	-3.10	3.51
July	3.23	-3.04	0.86	-1.21	-0.10
August	4.63	-1.25	-1.37	-0.05	-0.23
September	0.26	-2.71	-0.75	0.10	2.18
October	6.92	1.31	-2.34	-1.85	2.91

Risk Analysis

- There are a few ozone-sensitive species at the site, one of which is a bioindicator for ozone.

- The Sum06 index is generally below the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold in two years, the N100 count shows that the one-hour concentration of ozone never reached 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb and no years in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.

- Relationships between the 90-day Sum06 accumulation periods ozone level and soil moisture are difficult to assess because ozone exposure was relatively similar over most of the five years. Although the two years with the highest levels of ozone exposure also had the most months of drought, the bi-modal distribution of the levels of exposure make any conclusions about their association suspect. No relationships are apparent between the W126 index and soil moisture. In the highest ozone year, 1999, there was one month of mild drought, while the second highest year, 1998, had half the level of exposure and experienced five months of mild to severe drought. The lowest ozone years, 1995 and 1996, had the same level of exposure, but one had favorable conditions and the other had three months of mild to severe drought.

The low levels of ozone exposure at Everglades National Park make the risk of foliar ozone injury to plants low. Neither the Sum06 nor the W126 criteria are satisfied, exposures above 80 ppb were uncommon, and concentrations never reached 100 ppb.

If the level of risk increases in the future, American elder can be used as a bioindicator species.

VIRGIN ISLANDS NATIONAL PARK
(VIIS)

Plant Species Sensitive to Ozone

No sensitive species are listed for the site.

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
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	W126	N100
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Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for VIIS					
	1995	1996	1997	1998	1999
Sum06	-	-	-	0	0
W126	-	-	-	-	1
N60	-	-	-	-	0
N80	-	-	-	-	0
N100	-	-	-	-	0

Soil Moisture Status

The US Department of Agriculture's Palmer Z Index that was selected to indicate soil moisture status is not calculated for Virgin Islands.

Risk Analysis

- There are no ozone-sensitive species listed for the site.
- Ozone monitoring data indicate that exposure levels at the site are extremely low and the thresholds for the Sum06 and the W126 indices are not satisfied.
- The N-values for the site show that exposures are extremely low and that ambient concentrations do not reach 60 ppb. These levels of exposure will not injure vegetation.
- Associations between the levels of ozone exposure and soil moisture cannot be assessed since data are not available.

The low level of ozone exposure at Virgin Islands National Park makes the risk of foliar ozone injury to plants low. However, ozone data are extremely limited and additional data should be evaluated to confirm the risk assessment.